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Revenue management policies for the truck rental industry

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ABSTRACT

In this paper, we consider the problem of managing a fleet of trucks with different capacity to serve the requests of different customers that arise randomly over time. The problem is formulated via dynamic programming. Linear programming approximations of the problem are presented and their solutions are exploited to develop partitioned booking limits and bid prices policies. The numerical experiments show that the proposed policies can be profitably used in supporting the decision maker.

1. Introduction

Revenue management methods are very effective to help companies in finding optimal policies to allocate their products in a given planning horizon. Indeed, revenue management capacity control is used by companies for maximizing revenue, by optimally allocating constrained and perishable capacity on differentiated products/services, that are targeted to heterogeneous customer segments and generally sold through advance booking in the face of uncertain levels of demand for service. One of the fundamental capacity control decision is either accept or reject an arriving booking request for a specific service and, in the latter case, preserve the availability for probably more valuable demand in subsequent periods.

Today, revenue management plays an important role for service firms in many different industries. While airlines have the longest history of development in revenue management, the techniques also apply to other industries with similar business characteristics, such as hotels, restaurants and car rental, freight transportation and passenger railways, telecommunications and financial services, internet service provision, electric utilities, broadcasting and even manufacturing companies (Chiang et al., 2007).

McGill and van Ryzin (1999) give a comprehensive overview of the history of revenue management in transportation, where it has had the greatest impact.

In this paper, we apply revenue management methods and policies to a truck rental problem. We define, on the basis of the arrival process of the requests, the policy for either accept or reject a booking request of rent once it arrives. We address the question of how to coordinate the decisions on fleet management and to treat the randomness in the demand arrivals explicitly by decomposing the problem into time periods and assessing the impact of the current decisions on the future, through the managing of available capacity.

The problem addressed here is a dynamic resource allocation problem, that involves the assignment of a set of reusable resources (vehicles) to tasks (customer demands) that occur over time. The assignment of a resource to a task produces a reward, removes the task from the system, and modifies the state (typically, a geographical location) of the resource (Powell

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et al., 2002, 2007; Topaloglu and Powell, 2006; Powell, 2007, Chapter 12). We were confronted with this problem within the context of managing a fleet of trucks rented by a logistic operator to serve customers who request the freight transportation between different nodes in a network. It is a fleet management problem where a vehicle is assigned to a request from one location to another at a given time. The fleet is composed of different type of trucks. At each decision epoch, a certain number of customers arrive in, each requesting a transportation of a certain quantity of goods from a certain origin to a destination. Each customer demand can be satisfy with a truck with a capacity greater or equal to the request.

We give a dynamic formulation of the problem at hand. Dynamic models arise in a great variety of transportation applications as a result of the need to capture the evolution of activities over time. These models allow to find an answer to the following crucial question: "*Which truck should assign to a customer given the unknown but, probably, more profitable demand that will arrive in the system in the future?*" Due to "the curse of dimensionality", the dynamic programming model cannot be solved optimally. For this reason, in order to provide the decision maker with a tool useful in taking decisions, we develop a linear programming formulation of the problem and apply revenue management techniques to take the best decision.

The present work shares some similarities with that of Topaloglu and Powell (2006). However, the following main differences can be found. First of all, in Topaloglu and Powell (2006), it is assumed that the customers can ask for different types of vehicles, on the basis of their preferences. In our work, instead, the logistic operator, by evaluating appropriately the convenience, can decide to assign a truck of greater capacity to a certain customer. Indeed, an "upgrade" can take place. In addition, to address the problem under consideration, we do not follow the approximate dynamic programming approach used in Topaloglu and Powell (2006). In taking decisions we in fact adopt revenue management policies, based on booking limits and bid prices, that require to solve, dynamically, a linear programming model. A policy that allows the logistic operator to use the same truck to satisfy multiple demands is also devised. This possibility is not exploited in Topaloglu and Powell (2006).

The rest of the paper is organized as follow. In Section 2, the "Trucks Rental Problem" (TRP, for short) is introduced and its dynamic programming formulation is given. Section 3 contains the linear programming formulation for the TRP, together with the description of some revenue management policies, based on the solution of the linear problem. The theoretical issues of the proposed policies are also investigated. In the same section, a new policy that considers the "sharing", i.e. the possibility for the logistic operator of using a certain truck for serving multiple demand, is defined. New versions of the TRP, incorporating sharing and the repositioning of empty trucks, are also exploited in Section 4. Numerical experiments are presented in Section 5. Some concluding remarks are stated in Section 6. The paper ends with an appendix containing some theoretical properties of the policies presented in Section 3.

2. A dynamic programming formulation for the TRP

We consider the problem of a logistic operator that offers a transportation service from a given set of origins to a given set of destinations. The transportation service consists in renting trucks of different capacities to different customers on a given time horizon. Each customer is associated with a certain level of demand. At each time of the booking horizon, the transportation operator has to decide how to manage the overall capacity in the most profitable way, taking into account that complete information about the future demand are not available.

Let $O = \{1, \ldots, o\}$ be a given set of origins and let $E = \{1, \ldots, e\}$ denote a given set of destinations. It is assumed that $O \equiv E$, i.e. each node can be serve as origin and destination of the transportation request. The logistic operator transports goods from an origin $i, i \in O$ to a destination $j, j \in E$ by r types of trucks. A truck of type $k \in K = \{1, \ldots, r\}$ is associated with a given value of capacity $a(k)$, $k = 1, \ldots r$.

Customers can be viewed as partitioned in r different classes. A customer is of class k if he/she requires the transportation of a quantity q_k of goods, such that $a(k-1) < q_k \leqslant a(k)$, $k = 1, \ldots, r$ and $a(0) = 0$. The demand of a class k customer can be satisfied with trucks with capacity $a(k)$ or greater, i.e. an "upgrade" can take place. We also assume that customers requests cannot be partitioned among different trucks.

In each time period $t = 1, \ldots, T$ of the booking horizon, the logistic operator has to decide on accepting the request of transferring a given quantity of goods from $i \in O$ to $j \in E$ with departure time $\bar{t}$, $\bar{t} = 1, \ldots \overline{T}$, with the goal of maximizing the total revenue. In the sequel we will refer to $1, \ldots, \overline{T}$ as the "operation horizon", i.e. the horizon where the transportation service takes place. We assume that the booking horizon and the operation horizon do not overlap.

Let $A = [A^1|A^2|\ldots|A^r]$, $A \in \mathcal{R}^{r \times u}, u = r + (r-1) + \cdots + [r-(r-1)] = r^2 - \sum_{l=1}^{r-1} l = max_{prod}$ denote a binary matrix, partitioned in r sub-matrices. Each sub-matrix $A^k \in \mathcal{R}^{r \times [(r-k)+1]}$, $k = 1, \ldots, r$ contains the set of possible products to satisfy the demand of a class k customer. In particular, the first column of sub-matrix A^k is the product constituted by the truck of minimum capacity $a(k)$ useful to satisfy the demand of class k, whereas the last column is the product constituted by the truck of maximum capacity $a(r)$ that can be used to satisfy the class k customer.

We indicate each column of matrix A as $A_p p = 1, \ldots, max_{prod}$. Each element a_{kp}, $p = 1, \ldots, max_{prod}$ of matrix A is equal to one if truck k is used in product p and 0 otherwise. It is worth noting that a product indicates the type of truck that the logistic operator can use to satisfy the demand of a certain class k; in fact, due to the upgrade, a class k request can be satisfied with trucks of capacity k or greater. In particular, given a class k request, the products $p = v_{kmin}, \ldots, v_{kmax}$, with $v_{kmin} = (k-1)r - \sum_{s=1}^{k-1}[(k-1)-s] + 1$ and $v_{kmax} = kr - \sum_{s=1}^{k-1}[k-s]$, can be used to meet the customer demand.

The state of the system is described by a matrix $X = [X_1^1|X_2^1|\ldots|X_{|E|}^1|\ldots|X_1^{\overline{T}}|X_2^{\overline{T}}|\ldots|X_{|E|}^{\overline{T}}]$, each column $X_i^{\bar{t}} = (x_{i1}^{\bar{t}}, \ldots, x_{ir}^{\bar{t}})^\top$, $\forall i \in O$, $\bar{t} = 1, \ldots \overline{T}$ representing the capacity of node i at time $\bar{t}$. In particular $x_{ik}^{\bar{t}}$ is the number of trucks of type k, $k = 1, \ldots, r$ available at node $i \in O$ at time $\bar{t} = 1, \ldots, \overline{T}$.